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Big view of a small world

Carl Zeiss SMT on microscopy for nano

Below 32nm

Lithographic options

Chemical saviour

Materials below 32nm

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Inner space: the final frontier

Markus Wiederspahn of **Carl Zeiss SMT AG** describes how the ever shrinking needs of observation in emerging technologies are been met by one of the world's leading manufacturers of observational devices.

Do you remember the first landing on the moon? Are you fascinated by the small robotic vehicles that explore our neighbouring planets and send breathtaking images back to Earth? Are you also amazed at the multicoloured photos of distant galaxies provided by modern x-ray telescopes? Exploring the universe and advancing into an infinitely gigantic cosmos are probably the last great adventure confronting humankind.

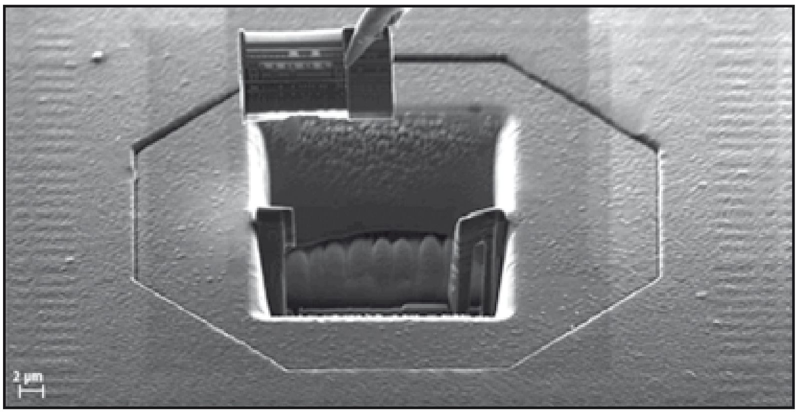
Anyone who has ever looked down a high power microscope knows better. Here, too, lies a strange and astounding universe. And this secret nanoworld would all remain hidden to us without such leading edge systems as electron microscopes or the breakthrough new technology of Helium-ion-microscopy.

A major application of these instruments lies in the world of micro or nanoelectronics. With ever shrinking feature sizes, already far below 100 nm, which is generally accepted as a definition for "Nanotechnology", a whole bunch of challenging tasks come in for the tools of the nanoworld. Whether it is basic research and development for the design of integrated circuits, materials research and development, process control, quality control, failure root cause analysis or even 3D reconstruction of probes, none of these tasks goes without leading edge imaging and analysis tools like SEMs, TEMs and CrossBeam Workstations, the latter combining the high resolution of SEM with focused ion beam operation. This suite of versatile tools has just recently been augmented by a completely new technology, ßHelium-ion-microscopy.

A new breed of microscope powered by a unique helium ion beam

Beam Scattering

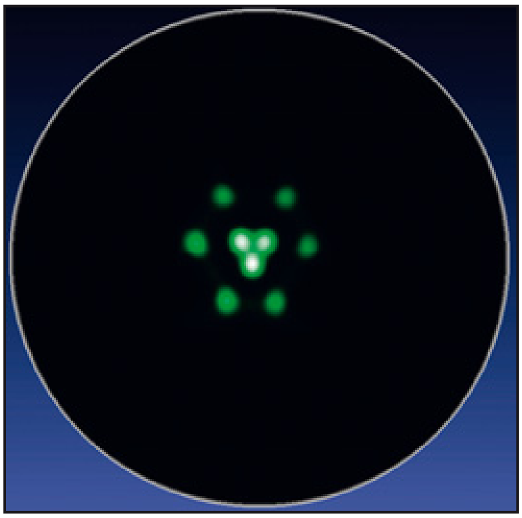
Imaging with charged particle beams, either electron or helium ion beams, is subject to a beam scattering effect. When the beam's primary particles strike the sample surface, they interact with the surrounding material, causing the emission of secondary electrons from an area that is somewhat larger than the size of the beam itself. The larger the area of surface interaction, the lower is the ultimate imaging resolution. Conversely, the smaller the area of surface interaction, the higher will be the ultimate image resolution. In the case of a SEM, the beam's electrons are scattered rapidly in the sample, resulting in secondary electrons being emitted from an area many times larger than the beam itself. Fortunately, when the helium ion beam strikes the sample with its larger and heavier particles, the particles do not scatter near the surface. This translates into a smaller area of surface interaction and much higher resolution images for the helium ion microscope.



CrossBeam operation: In-situ lift out: After milling and polishing the lamella is cut out and picked up with a precision micromanipulator tip

Material Contrast

Although the area of surface interaction for the helium ion beam is relatively small, compared to a typical SEM, the total number of secondary electrons produced is greater. This larger secondary electron yield, and the large difference in yield between different materials, provides higher contrast imaging, making it easier to



differentiate between materials with the helium ion microscope. In addition, the helium ion microscope can collect backscattered helium ions, much like in Rutherford Backscattered Spectroscopy. With proper selection and positioning of the detector, the total backscattered ion yield is directly proportional to the mass of the sample atoms. Using this imaging mode, it is possible to easily differentiate between sample materials.

The 'Trimer'

The ZEISS ORION Helium ion icroscope is based on the revolutionary, atomic-sized, ALIS gas field ion source. The secret to the amazing resolving power of the helium ion beam starts with the source tip. A finely sharpened needle is made even sharper through a proprietary process that took years to develop. Individual atoms are stripped away from the source until an atomic pyramid is created with just three atoms at the very end of the source tip, a configuration called the 'trimer'. This repeatable process can be accomplished in-situ. Once the trimer is formed, the tip is maintained under high vacuum and cryogenic temperatures with helium gas flowing over it. A high voltage is applied to the needle to produce an extremely high electric field at its apex. The helium gas is attracted to the energised tip where it is ionised. With ionisation happening in the vicinity of a single atom, the resulting ion beam appears to be emanating from a region that is less than an angstrom in size. This produces an extremely bright beam that can be focused to an extraordinarily small probe size.

Column

This ALIS source is mated with an advanced electrostatic ion column that focuses the beam with sub-nanometer precision. Much like a SEM, the beam is rastered across the sample pixel by pixel. The number of detected secondary electrons is used to determine the gray level of that particular pixel. Since the number of detected secondary electrons varies with material composition and shape, the images provide excellent topographic and compositional information.

Diffraction

Helium ions are about 8000 times heavier than electrons. Because of this, a helium ion beam exhibits very little diffraction when passed through an aperture or across an edge. Diffraction is a significant problem for a SEM where the diffraction effect limits its ultimate spot size. Since the helium ion beam is not affected by diffraction, it can be focused to a much finer spot size, enabling sub-nanometer resolution.

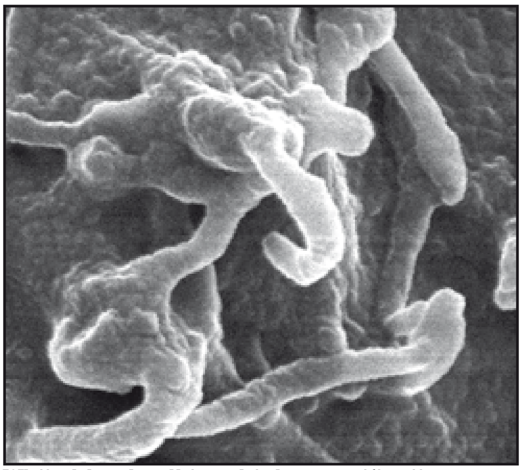
Long Source Lifetime

The helium ion source has a very long lifetime due to the fact that the source tip is always kept at a positive potential. The only things attracted to the tip are electrons, which do not cause any ill effects. Positively charged ions are repelled from the tip and other gasses will be ionised before they have a chance to strike the source tip. For this reason, the source lifetime for the helium ion source is well over 1000 hours.

NVision 40, a new way of combined competencies and application possibilities

However, imaging with a resolution down to the one digit nanometer region and below is just one of the needs when developing and producing densely packed integrated circuits on silicon. Some key words describe the numerous tasks, that can be perfectly ac complished with another kind of leading edge tools, so called CrossBeam workstations:

- Materials analysis and characterization
- Nanomanipulation and nano probing



White blood cell in a high magnification captured with the ORION He-Ion microscope

- TEM sample preparation
- 3D reconstruction
- Ion beam lithography/micromachining
- Life imaging during milling process
- Depositing and etching

The NVision 40 CrossBeam workstation units imaging and analytical capabilities of the high resolution field emission GEMINI SEM of Carl Zeiss SMT with the high performance zeta FIB column of SIINT. Together with the new SIINT GIS supporting liquid, solid state and gaseous precursors as well as gas mixing technology and carbon free SiO2 deposition the NVision 40 represents a powerful tool for 3D nanoscale high resolution imaging, structuring and analytics.

The system features a dome type chamber design and a pendulumn vibration insulation system for enhanced stability. Numerous access ports for various detectors (EDS, EBSD, STEM, 4QBSO) as well as sample manipulation and probing systems ensure full support for analytical and micromanipulation needs. The system is a highly valuable platform for today's and future nanotechnology needs.

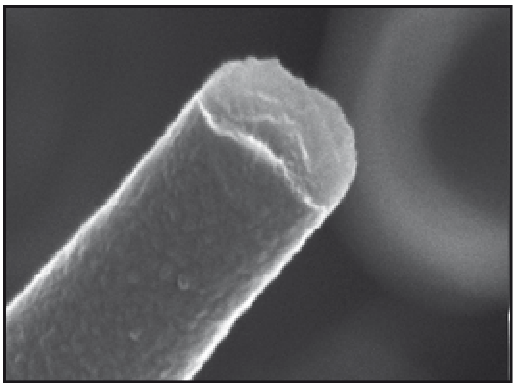
Imaging

The GEMINI electron optics offers high resolution with excellent contrasts even at low voltages (2,5 nm @ 1 kV). The Multi-mode STEM detector allows simultaneous bright-field and dark-field imaging as well as oriented dark-field imaging (ODF). By using FESEM and FIB simultaneously the ion milling process can be controlled by live high resolution imaging at nanoscale level. This means highest productivity thanks to 100% control for end point detection. The in-lens SE and EsB detectors allow simultaneous SE and BSE imaging for comprehensive sample characterization in one shot, especially at ultra low voltages for high surface sensitivity, short WDs, and with tilted stage.

Structuring

The zeta FIB column with its accelerating objective lens technology offers a resolution of 4 nm with up to 20% increased current densities with respect to

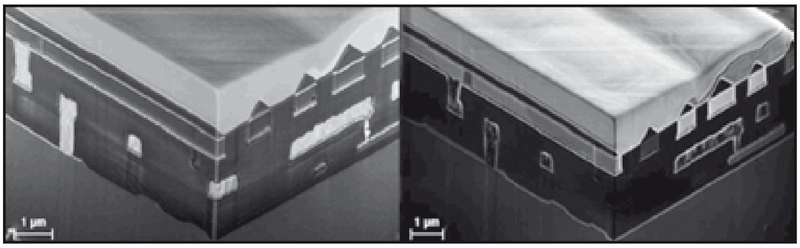
conventional ion optics. This combined with the low voltage FIB performance significantly impacts time to the sample and the sample quality.



Finest details of Low-Z materials like Carbon Nanotubes can be seen with the aid of the Helium-Ion microscope.

TEM Sample Preparation

A highly relevant feature for quality control of the chip-manufacturing process is TEM sample preparation. Due to the patent protected design of the GEMINI e-beam column, simultaneous high resolution SEM imaging during FIB milling is performed, allowing for control of the FIB milling process and end-point detection. The risk of destroying a sample during preparation is reduced. In addition the ion milling process can be automated by using the sophisticated automation routines provided in SmartSEM software. By adding internal Lift-out tools to the tool the whole TEM preparation process can be handled in-situ inside the vacuum of the instrument.



Cross section through a semiconductor device. SEM image on the left and FIB image on the right. The FIB image provides additional voltage contrast information. Note the bright and dark metal lines on the right image

3D Reconstruction

FIB-SEM tomographic reconstruction provides a powerful tool to visualise complete 3D volumetric data at a resolution of down to 10 nm or better in all three dimensions. The method employs SEM image data acquired during stepwise sectioning a volume of interest using FIB milling. One of the the most exciting evolutions in this field is the use of the unique EsB detector for collecting sample information conveyed by backscatted electrons. The EsB detector produces a low voltage, short working distance, high-resolution compositionally weighted image signal with minimal topographic contrast. In addition to being possibly the ideal signal for 3D FIBSEM tomography, it opens new opportunities for biological and life science samples through the ability to distinguish contrast associated with various forms of organic materials while providing maximum charge control.